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DOMESTIC WASH-WATER RECLAMATION USING AN AEROSPACE-DEVELOPED WATER RECOVERY SUBSYSTEM

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16. Abstract

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SUMMARY

A prototype aerospace distillation water recovery subsystem has been tested to determine its capability to recover potable water from domestic wash water. A total of 0.0994 m^3 (26.25 gallons) of domestic wash water was processed over a 7-day period at an average process rate of 0.0146 m^3 per day (3.85 gallons per day). The subsystem produced water that met all United States Public Health Standards for drinking water with the exception of two standards which could not be analyzed at the required sensitivity levels. Average energy consumption for this evaluation to maintain both the recovery process and microbial control in the recovered water was approximately 3366 kilowatt-hours per cubic meter (12.74 kilowatt-hours per gallon) of water recovered. This condition represents a worst case energy consumption since no attempt was made to recover heat energy in the subsystem. An ultraviolet radiation cell installed in the effluent line of the subsystem was effective in controlling coliform micro-organisms within acceptable levels for drinking water. The subsystem recovered virtually 100 percent of the available water in the waste-water process. In addition, the subsystem removed 99.6 percent and 98.3 percent of the surfactants and phosphate, respectively, from the wash water.

INTRODUCTION

Pollution of natural water supplies has become an area of increasing concern over the last several years. The increase in demand for this natural resource caused by increases in both population and industrial needs is diminishing the supply of unpolluted water at an alarming rate. One concept that could lead to conserving potable water and reducing this pollution is the reclamation of waste water in households. National Aeronautics and Space Administration has developed prototype low process capacity water-reclamation subsystems (refs. 1 to 3) in conjunction with the manned space program which could have possible application to this problem. The purpose of this investigation is to determine the capability of one of these subsystems to reclaim potable water from domestic wash water. The subsystem tested during this investigation was designed to reclaim the daily urine and flush water output of a four-man crew in a zero-gravity environment. (See ref. 3.) The subsystem utilized an evaporator in a closed heated airstream to separate the contaminants from the waste water. The rationale for the design included operation with waste heat provided by an advanced power generation concept for manned space stations. (See ref. 4.) Therefore, no provisions were contained in the subsystem itself to recover heat energy to reduce the power required to maintain the evaporative process. This report presents the data obtained from the investigation in which both baseline and wash-water tests were performed over near-constant operating conditions. The baseline tests were performed with tap water and detergent and the wash-water tests were performed with the waste water resulting from four shower baths and one wash load of clothes. The data include chemical, physical, and microbiological analyses of both the waste and recovered waters. Also included is a comparison of the quality of the recovered water with the U.S. Public Health Standards given in reference 5.

SUBSYSTEM DESCRIPTION

A schematic drawing of the test setup used in this investigation is shown in figure 1, which includes the water reclamation subsystem and associated support equipment used to collect and process the waste water. Figure 2 shows a view of the processing equipment which includes the evaporator, control panel, and recovered-water tank. There were three basic circuits provided in the subsystem to allow recovery of the waste water: (1) a waste-water feed control circuit to maintain sufficient waste water in the evaporator to sustain the distillation process; (2) an air circuit to provide the transport medium to separate the contaminants from the wash water; and (3) a processed water circuit with capability to maintain micro-organism control in the recovered water. In the waste-water feed control circuit, waste water was fed into the evaporator by a pump which was automatically activated through load sensors located under the evaporator. These sensors produced electrical signals which were proportional to the variation in the weight of waste water in the evaporator. High and low set points were provided in the electrical circuits that matched the weight range of waste water desired in the evaporator. When the low set point was reached, the pump was energized and waste water was added to the evaporator until the high set point was reached. At this time, the pump was deenergized; thus, the flow of waste water into the evaporator was terminated. This process was repeated throughout the test as waste water was required for processing. In the air circuit, air was circulated through a closed loop with an electrically driven fan. The air passed through an electrical heater to increase its moisture-carrying capacity prior to passing through the evaporator. The evaporator consisted of a stainless-steel container surrounding a wick core which was configured to provide approximately 0.232 m^2 (2.50 ft^2) of evaporative surface area. (See fig. 3.) The wicking material was rayon felt, and the filler material in the longitudinal passages which allowed air to pass through the wick was porous urethane foam. The wick core dimensions were 6.99 by 39.05 by 50.17 cm (2.75 by 15.375 by 19.75 inches) and it weighed 1.20 kg (2.64 lb). Waste water was fed into the wick core through a manifold which was an integral part of the upper evaporator cover. Water was evaporated as the heated air passed through the wick; thus, the contaminants remained in the wick. Eventually, the wick core has to be replaced as it becomes loaded with these contaminants. The nearly saturated air then passed through a condensing heat exchanger where the water vapor was condensed from the airstream. The resulting water droplets were entrained in the airstream and transferred to an air-driven centrifugal air-water separator. The water droplets were then removed from the airstream by the separator and the air was returned to the fan for recirculation through the closed air circuit. In the processed-water circuit, the air-water separator pumped the processed water through an ultraviolet radiation cell into a collecting tank. The radiation cell, which had an average germicidal energy rating in excess of 25 000 microwatts per cm^2 at a water flow-through rate of 0.0181 m^3 per minute (161 290 microwatts per in^2 at 4 gallons per minute), was used to control micro-organisms in the recovered water.

TEST SETUP AND INSTRUMENTATION

A schematic drawing of the test setup is shown in figure 1. Clothes were washed in a commercial washing machine and showers were taken in a domestic shower stall. Both of these facilities were connected to the local municipal water supply. Hot water was supplied by a 0.151-m^3 (40-gallon), 4000-watt hot water heater. Two dial-type temperature gages were installed before the water use facilities to determine the temperatures of both the hot and cold water. Cold-water quantities were obtained with an integrating flowmeter installed as shown in figure 1. This meter reading was recorded before and after each washing activity. Total water quantities were obtained by measuring the water collected in the 0.303-m^3 (80-gallon) waste-water tank after each washing activity. Hot-water quantities were then estimated from the differences between the cold water measured with the flowmeter and the total water measured in the waste-water tank.

Two iron-constantan thermocouples, located as shown in figure 1, were used to determine operating temperatures of the water-reclamation subsystem. The outputs from the thermocouples were monitored on a strip-chart recorder. The power consumption of the air heater was monitored by a watt meter connected across one phase of the 208-volt, 400-hertz (400-cps) three-phase input. The quantity of wash water in the evaporator was determined from the output of three strain-gage load cells mounted under the evaporator. The load cells were electrically connected in parallel and were continuously monitored on a strip-chart recorder. Process rates were determined daily by weighing the quantity of water accumulated in the recovered-water tank over a 24-hour period. Cooling for the condensing heat exchanger was supplied by a closed fluid loop. The cooling fluid was 25 percent (by volume) aqueous propylene glycol.

TEST METHOD

The subsystem was operated over a 9-day period to obtain data for both baseline and wash-water tests. Operation was continuous except for 5 hours during test 3 when the subsystem was shut down for maintenance. The baseline tests were performed prior to the wash-water tests to determine whether the tap water, clothes washing detergent, and the equipment included in the test setup were contributing contaminants to the test system. Performance data were recorded manually at 0.5-hour intervals during the first two work shifts of attended operation. During the third shift, the subsystem was unattended, and data were recorded automatically on strip-chart recorders. Samples of both the waste water (sample port 1) and the recovered water (sample port 4) were taken daily for chemical and physical analyses. The residual water remaining in the recovered-water tank (see fig. 1) after the samples were taken was dumped daily prior to the start of recovered-water collection for the next 24-hour processing period. Daily water samples were also obtained for microbial analysis (sample ports 1, 2, and 3). A clean dry wick core was weighed and installed in the evaporator housing at the start of the test program and was used for all the tests.

The initial baseline test, test 1, was performed with municipal tap water. The shower and washing machine were operated through their normal wash cycles except that no one was in the shower stall and no clothes or detergent were added to the washing machine. A portion of the water accumulated was processed through the water-recovery subsystem for 24 hours. Prior to the start of processing, the wick core was manually filled with 0.0034 m^3 (0.90 gallon) of the tap water. This quantity represents 65-percent saturation of a clean wick core as observed visually. This quantity of waste water was automatically maintained in the wick core for the subsequent tests. The second baseline test, test 2, was identical to test 1, except that sufficient tap water was added to the waste-water tank through the shower stall to replace the water that had been removed during test 1. In addition, clothes washing detergent in the amount of 0.10 kg (0.22 lb) was added directly to the waste-water tank and thoroughly mixed for 5 minutes by bubbling air through the water. The method of performing these tests was similar to that for wash-water tests 3 and 4 which are described in the following paragraph.

The test method for tests 3 and 4 were identical, except that a different brand of bath soap was used in providing the shower water for each test. Wash water resulting from four shower baths and the washing of one load of clothes was collected in the waste-water tank. The wash water was then automatically supplied to the wick core on demand.

When 0.00042 m^3 (0.11 gallon) of wash water had been evaporated, the feed control would automatically refill the wick core to the original quantity of 0.0034 m^3 (0.90 gallon). The subsystem was operated in this manner for 91 hours during test 3 and for 72 hours during test 4.

RESULTS AND DISCUSSION

Table I gives a summary of the water-reclamation subsystem operational data, table II gives a summary of the wash water collected, and table III gives a summary of the chemical and physical parameters of the waste and recovered waters. Data shown in table III for the two baseline tests are the same as those given in appendix A since only 1 day of testing was performed with tap water and only 1 day of testing was performed with the detergent added to the tap water. Wash-water tests, tests 3 and 4, show averaged values of the data given in appendix A for each sample port location. The chemical and physical parameters were measured by standard methods of analysis as described in reference 6. A summary list of these techniques along with the lower detection limits achievable in the water analysis laboratory at the Langley Research Center are given in table IV. Table V shows viable micro-organism counts for sample port locations 1, 2, and 3. These values were obtained by averaging the data for all the tests for these sample ports as given in appendix B. The total micro-organism counts were obtained by making tenfold dilutions of the samples in 0.05 percent peptone water and plating appropriate dilutions on Trypticase soy agar. Colonies were counted after 48 hours incubation at 308.2 K (95° F) and the results were expressed as the total number of micro-organisms per milliliter of sample. Coliform micro-organism counts were obtained by using the membrane filter technique as described in reference 6.

Subsystem Operational Data

Shown in table I is a summary of the water-reclamation subsystem operational data which includes process temperatures, power consumed, process times, and the quantities of water recovered daily. During the wash-water tests, tests 3 and 4, a total of 0.0994 m^3 (26.25 gallons) of wash water was processed over a 7-day period for a recovery efficiency of virtually 100 percent. The water recovery efficiency of the subsystem is defined as the volume ratio of the water recovered to the wash water actually processed.

The daily wash-water process rates averaged 0.0146 m^3 per day (3.85 gallons per day). Associated subsystem average operating temperatures for the evaporator air inlet temperature and the condenser air outlet temperature were 338.0 K (148.7° F) and 284.1 K (51.7° F), respectively.

The power required to maintain the water recovery process and control microorganisms in the recovered water averaged 2.044 kW. This value included an average 0.729 kW to operate the air heater, 0.075 kW to operate the fan, 1.200 kW to operate the cooling unit, and 0.040 kW to operate the ultraviolet radiation cell. The power value for the air heater was measured during the test program whereas the other power values were approximated subsequent to the test program by measuring the power required by these components under virtually the same operating conditions. The average energy required by these components to process the wash water (tests 3 and 4) was 3366 kilowatt-hours per cubic meter (12.74 kilowatt-hours per gallon). The power required for heating the wash water and operating the washing machine was not charged to processing the wash water. Although the electrical power required appears to be high, redesign of the process to incorporate features to recover both latent and sensible heat energy would substantially reduce power consumption. In addition, modification of the process to operate on waste heat from future onsite power-generation and waste-treatment facilities for small communities would also minimize the electrical power required.

Wash-Water Collection and Quality

Two separate wash-water collections, each consisting of the water provided from four shower baths and washing one load of clothes, were used for tests 3 and 4. (See table II.) A different brand of biodegradable bath soap was used for shower bathing whereas the same clothes washing detergent was used for both tests. The quantity of wash water resulting from each collection was used as being representative of the daily amount and composition anticipated for the average size family of four people as defined in reference 7.

Langley Research Center personnel provided the bath water by bathing in a domestic shower stall. The water collected from the stall averaged 0.0356 m^3 (9.4 gallons) per shower of which 0.0201 m^3 (5.3 gallons) was hot water. Soap consumption averaged 0.014 kg (0.03 lb) per shower.

Clothes wash water was obtained by washing soiled clothes in a commercial washing machine. Both colored and white clothing obtained from the family of one Langley Research Center employee were washed during this investigation. Clothing washed averaged 52.6 kg (11.6 lb) per wash load. Water quantity used to wash the clothes averaged 0.110 m^3 (29.0 gallons) per wash load of which 0.0643 m^3 (17.0 gallons) was hot water. Hot and cold water temperatures at the inlet to the water use appliances averaged 332.9 K (139.5° F) and 291.5 K (65° F), respectively. The detergent used to wash the clothes averaged 0.10 kg (0.22 lb) per wash load. This cleansing agent was formulated by thoroughly mixing equal volumes of 16 commercially available dry detergents. The detergent added significant quantities of phosphate, sulfate, methylene blue active substances (MBAS), total organic carbon, and all physical parameters except odor to the waste water. (See table III, tests 1 and 2, sample port 1.)

The parameters measured in the waste water from the shower baths and washing clothes are given in table III. (See tests 3 and 4, sample port 1.) Comparison of these data with the data obtained from test 2, sample port 1, shows that the addition of the clothes, the shower subjects, and bath soap to the washing activities results in wash water with significant increases in iron, zinc, ammonia, oil and grease (carbon chloroform extract), total organic carbon, urea, and all physical parameters with the exception of pH. In addition, the solids in the wash water as determined by the solids retained in the wick for the wash water processed was 0.114 percent by weight. It is of interest to note that the waste water including these increases still meets 10 out of 23 of the chemical and physical requirements established for potable water in reference 5.

Recovered-Water Quality

The potable water standards established by the U.S. Public Health Service in reference 5 were used to determine water quality during this investigation. The water was analyzed for 22 out of 23 of these requirements. An analysis for phenols was not performed because of an insufficient analytical capability to measure the maximum levels specified for phenols in reference 5. It is also significant to note that although the analysis for carbon chloroform extract was performed, the sensitivity of the method available to measure this parameter was not low enough to detect the maximum levels specified for this standard. In addition, the water was analyzed for nine other parameters which were selected to give additional subsystem performance information. These were ammonia, calcium, conductivity, magnesium, nickel, pH, phosphates, total organic carbon, and urea. Although these parameters were not included in reference 5, they are presented in case they should be included in future water-quality standards. The subsystem removed in excess of 98.3 percent of the phosphate from the wash water. Phosphate is one of the major pollutants found in sewage.

The results indicate that the water-recovery subsystem described in this report can recover water that meets 21 out of 23 of the chemical and physical requirements established for potable water. The capability of the subsystem to recover water that meets two requirements, namely, carbon chloroform extract and phenols, could not be determined for reasons previously discussed. The subsystem removed 99.6 percent of the surfactants (methylene blue active substances) from the wash water.

Micro-Organism Control

Table V shows both the averaged total viable micro-organism counts and the averaged viable coliform counts for the water analyzed from sample ports 1, 2, and 3 during this evaluation. These values were obtained by averaging the micro-organism counts given for these sample ports in appendix B for all the tests.

Micro-organisms were reduced with an ultraviolet radiation cell installed in the processed water line. The effectiveness of the radiation cell to reduce and in some cases eliminate micro-organisms from the processed water is shown in table V. Comparisons of these data for sample ports 2 and 3 show that the radiation cell reduced the total micro-organism counts from 10^5 to 10^4 cells per milliliter and the coliform counts from 10^5 to 0 cells per milliliter in the recovered water. The recovered-water dwell time in the radiation cell, which was calculated from the daily average process rate and cell geometry, was approximately 3 hours. Further examination of table V, sample port 3, shows that the radiation cell was effective in reducing the coliform micro-organisms below the maximum levels given in reference 5 for potable water. No attempt was made to classify the other types of micro-organisms remaining in the recovered water since reference 5 contains no microbial standards for drinking water other than coliform micro-organisms.

The high cell counts in the waste water (sample port 1) for the baseline tests are residual micro-organisms resulting from prior use of the shower stall and the washing machine. No attempt was made to sterilize these appliances or the processing equipment prior to the start of the test program.

CONCLUDING REMARKS

An evaluation of a prototype aerospace distillation water reclamation subsystem designed for use on extended manned space missions has been conducted to determine its capability to reclaim potable water from domestic wash water. The subsystem produced water that met all the chemical and physical requirements for drinking water established by the U.S. Public Health Service with the exception of carbon chloroform extractables and phenols. These two requirements were not determined because of a lack of capability to measure the concentration levels specified for these standards. The ultraviolet radiation cell was effective in controlling viable coliform micro-organisms in the recovered water below the maximum levels specified for drinking water. The electrical power requirements were high, but redesign of the process to incorporate features to recuperate heat energy or operate on waste heat from future onsite power-generating facilities for small communities would substantially reduce these requirements. The subsystems recovered virtually 100 percent of the available water in the wash water processed. In addition, the subsystem removed 99.6 percent and 98.3 percent of the surfactants and phosphate, respectively, from the wash water.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., August 20, 1973.

APPENDIX A

CHEMICAL AND PHYSICAL WATER DATA

Data included in this appendix were obtained from the chemical and physical water analysis for both the baseline and wash-water tests. Data are presented which show the condition of the water before and after processing. The analysis includes 22 of the 23 parameters listed in reference 5 for potable water. In addition, data are included for nine other parameters which were selected to give additional subsystem performance information.

The data from the metals analysis are given in the following table:

Parameter	Unit	U.S. Public Health Standard (ref. 5)	Sample port (see fig. 1)	Baseline test 1, tap water for sample[a]	Baseline test 2, tap water and detergent for sample[a]	Test 3, wash water for sample[a]				Test 4, wash water for sample[a]		
				A	A	A	B	C	D	A	B	C
Arsenic	ppm	0.05	1	<0.010	<0.010	(b)	(b)	(b)	(b)	(b)	(b)	(b)
			4	<0.010	<0.010	<0.011	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Barium	ppm	1	1	<1	<1	<1	<1	<1	<1	<1	<1	<1
			4	<1	<1	<1	<1	<1	<1	<1	<1	<1
Cadmium	ppm	0.01	1	0.03	0.03	<0.01	<0.01	0.02	<0.01	0.01	0.02	0.02
			4	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.01	<0.01	<0.01
Chromium	ppm	0.05	1	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
			4	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Copper	ppm	1.00	1	0.51	0.50	0.41	0.51	0.46	0.46	0.39	0.29	0.30
			4	0.34	0.25	0.23	0.19	0.21	0.23	0.19	0.22	0.09
Iron	ppm	0.30	1	0.76	0.86	1.50	1.30	0.82	0.80	0.95	0.88	0.92
			4	0.06	<0.05	0.07	0.07	0.05	0.06	<0.05	<0.05	<0.05
Lead	ppm	0.05	1	0.20	0.10	0.03	0.10	0.02	0.02	0.02	0.10	0.20
			4	0.02	0.02	0.01	0.04	0.02	0.02	0.02	0.03	0.04
Magnesium	ppm	None	1	4.4	4.1	5.4	5.1	5.0	4.9	3.6	3.5	3.5
			4	0.07	0.07	0.14	0.23	0.09	0.29	0.10	0.11	0.24
Manganese	ppm	0.05	1	<0.05	<0.05	<0.05	0.06	0.05	0.06	<0.05	<0.05	<0.05
			4	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Nickel	ppm	None	1	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
			4	0.34	0.10	0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Selenium	ppm	0.01	1	<0.01	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)
			4	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Silver	ppm	0.05	1	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
			4	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Zinc	ppm	5.00	1	0.30	0.30	0.70	0.70	0.40	0.76	0.70	0.73	0.74
			4	0.05	0.03	0.05	0.08	0.06	0.07	0.05	0.03	0.05

[a]A, B, C, and D designate daily samples.

[b]Analysis not performed.

The data from the ions analysis are presented in the following table:

Parameter	Unit	U.S. Public Health Standard	Sample port (see fig. 1)	Baseline test 1, tap water for sample[a]	Baseline test 2, tap water and detergent for sample[a]	Test 3, wash water for sample[a]				Test 4, wash water for sample[a]		
				A	A	A	B	C	D	A	B	C
Ammonium	ppm	None	1	0.2	0.5	0.6	0.5	1.4	1.0	1.9	1.0	1.2
			4	2.5	1.3	0.6	1.6	1.0	1.5	0.9	1.6	1.4
Calcium	ppm	None	1	28	28	33	30	28	28	29	29	29
			4	0.2	0.2	1.2	1.0	0.3	1.2	0.6	0.5	1.1
Chloride	ppm	250	1	31	46	50	42	45	45	37	44	43
			4	<5	<5	<5	<5	<5	<5	<5	<5	<5
Cyanide	ppm	0.20	1	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
			4	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Fluoride	ppm	1.70	1	0.75	0.86	0.80	0.77	0.70	0.80	0.80	0.80	0.80
			4	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Nitrate and nitrite	ppm	45.0	1	0.4	0.4	0.6	<0.2	<0.2	<0.2	<0.2	0.2	<0.2
			4	0.3	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.2
Phosphates	ppm	None	1	4	100	130	105	110	110	90	95	95
			4	0.1	<0.1	0.6	3.0	<0.1	5.0	0.9	1.3	3.0
Sulfate	ppm	250	1	12	74	71	85	65	60	66	74	95
			4	<5	<5	<5	<5	<5	<5	<5	<5	<5

[a]A, B, C, and D designate daily samples.

The data from the organic and physical analysis are presented in the following table:

Parameter	Unit	U.S. Public Health Standard	Sample port (see fig. 1)	Baseline test 1, tap water for sample[a]	Baseline test 2, tap water and detergent for sample[a]	Test 3, wash water for sample[a]				Test 4, wash water for sample[a]		
				A	A	A	B	C	D	A	B	C
Organic analysis												
Carbon chloroform extract	ppm	0.20	1	<10	<10	11	84	53	54	99	65	71
			4	<10	<10	<10	<10	13	<10	<10	<10	<10
Methylene blue active substances	ppm	0.50	1	0.04	27	30	30	30	21	24	27	27
			4	<0.01	0.02	0.10	0.20	0.01	0.30	0.01	0.10	0.15
Phenols	ppm	0.001	1	Analysis not performed								
			4									
Total organic carbon	ppm	None	1	7	40	200	110	125	150	95	115	100
			4	18	<5	9	9	<5	8	5	5	6
Urea	ppm	None	1	<1	<1	<1	2	3	<1	<1	<3	4
			4	<1	<1	<1	<1	<1	<1	<1	<1	<1
Physical analysis												
Color	$PtCl_6$ equivalent units	15	1	30	50	>100	>100	>100	>100	>100	>100	>100
			4	<5	<5	<5	5	<5	10	<5	<5	<5
Conductivity	Micromhos per centimeter	None	1	225	440	560	520	520	500	490	425	470
			4	9	6	13	27	5	42	10	16	33
Odor	Threshold number	3.0	1	<3	<3	>3	>3	>3	>3	>3	>3	>3
			4	<3	<3	<3	<3	<3	<3	<3	<3	<3
pH	pH	None	1	7.8	9.1	8.1	6.7	6.8	6.8	7.8	7.2	7.2
			4	5.7	4.7	5.6	6.5	6.2	6.8	6.3	6.5	6.6
Total solids	ppm	500	1	206	501	902	776	771	680	782	696	686
			4	<100	<100	<100	<100	228	<100	<100	<100	<100
Turbidity	ppm, SiO_2 equivalent units	5.0	1	8.3	41	280	270	260	225	240	200	200
			4	0.63	0.27	1.90	1.90	0.50	6.80	1.00	1.40	2.50

[a]A, B, C, and D designate daily samples.

APPENDIX B

MICRO-ORGANISM DATA

Included in this appendix are data obtained from the micro-organism analyses of water samples obtained at various intervals during the tests. Data are presented which show total viable cell counts as well as viable coliform counts for both the waste and processed waters.

Micro-organism measurement	U.S. Public Health Standard	Sample port (see fig. 1)	Baseline test 1, tap water for sample[a]		Baseline test 2, tap water and detergent for sample[a]	Test 3, wash water for sample[a]				Test 4, wash water for sample[a]		
			A	B	B	B	C	D	E	B	C	D
Total cells/ml	None	1	3.48×10^5	1.96×10^5	1.97×10^6	2.82×10^6	5.00×10^5	5.80×10^6	4.69×10^6	3.40×10^6	2.16×10^6	1.58×10^6
Coliform cells/100 ml	<4	1	$>8.0 \times 10^3$	$>8.0 \times 10^3$	2.8×10^6	6.5×10^7	8.1×10^6	1.5×10^7	3.0×10^5	1.3×10^6	3.7×10^6	2.5×10^6
Total cells/ml	None	2	Not performed		Not performed	6.07×10^5	7.60×10^4	8.30×10^4	8.10×10^5	1.58×10^5	$>6.00 \times 10^4$	3.80×10^5
Coliform cells/100 ml	<4	2	Not performed		Not performed	4.4×10^6	0	3.0×10^3	8.0×10^3	2.09×10^4	$>8.0 \times 10^4$	3.60×10^4
Total cells/ml	None	3	Not performed	0	0	1	1.39×10^2	1.60×10^2	1.82×10^3	1.52×10^3	3.30×10^3	9.60×10^4
Coliform cells/100 ml	<4	3	Not performed	0	0	2	0	0	0	0	0	0

[a]Sample A was taken at start of tests; samples B, C, D, and E are daily samples.

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TABLE I.- SUMMARY OF THE WATER-RECLAMATION SUBSYSTEM OPERATIONAL DATA

[Data averaged daily]

Type of waste water	Test	Evaporator air inlet temperature		Condenser air outlet temperature		Power, kW				Process time, hrs	Water recovered	
		K	°F	K	°F	Air heater	Fan	Radiation cell	Cooling unit		m^3	gal
Baseline, tap water	1	338.7	150	283.2	50	0.741	0.075	0.040	1.200	24	0.0148	3.92
Baseline, tap water and detergent	2	338.2	149	283.2	50	0.690	0.075	0.040	1.200	24	0.0155	4.10
Wash water	3	337.1	147	286.0	55	0.702	0.075	0.040	1.200	19	0.0103	2.73
		338.2	149	283.2	50	0.723	0.075	0.040	1.200	24	0.0152	4.01
		338.2	149	283.2	50	0.720	0.075	0.040	1.200	24	0.0147	3.87
		337.6	148	284.3	51	0.765	0.075	0.040	1.200	24	0.0160	4.22
	4	337.6	148	282.1	48	0.748	0.075	0.040	1.200	24	0.0143	3.78
		339.8	151	286.0	55	0.728	0.075	0.040	1.200	24	0.0143	3.78
		338.2	149	284.8	53	0.720	0.075	0.040	1.200	24	0.0146	3.86

TABLE II.- SUMMARY OF WASH WATER COLLECTED

Type of waste water	Test	Volume of shower water used				Volume of clothes wash water used				Weight of clothes washed	
		Hot[a]		Cold[b]		Hot[a]		Cold[b]			
		m^3	gal	m^3	gal	m^3	gal	m^3	gal	kg	lb
Baseline, tap water	1	0.0401	10.6	0.0734	19.4	0.0375	9.9	0.0836	22.1	0	0
Baseline, tap water and detergent	2	0	0	0.0454	12.0	0	0	0	0	0	0
Wash water[c]	3	0.0678	17.9	0.0609	16.1	0.0700	18.5	0.0397	10.5	4.35	9.6
Wash water[c]	4	0.0927	24.5	0.0625	16.5	0.0583	15.4	0.0515	13.6	6.12	13.5

[a]Hot water temperature averaged 332.9 K (139.5° F).

[b]Cold water temperature averaged 291.5 K (65° F).

[c]Wash water obtained from four shower baths using an average of 0.014 kg (0.03 lb) of soap per shower, and one wash load of clothes using 0.10 kg (0.22 lb) of detergent per wash load.

TABLE III.- SUMMARY OF CHEMICAL AND PHYSICAL WATER DATA

(a) Metals

Parameter	Unit	U.S. Public Health Standard	Sample port (see fig. 1)	Baseline test 1, tap water	Baseline test 2, tap water and detergent	Test 3, wash water	Test 4, wash water
Arsenic	ppm	0.05	1	<0.01	<0.01	Not performed	
			4	<0.01	<0.01	<0.01	<0.01
Barium	ppm	1	1	<1	<1	<1	<1
			4	<1	<1	<1	<1
Cadminum	ppm	0.01	1	0.03	0.03	<0.013	0.017
			4	<0.01	<0.01	<0.010	<0.01
Chromium	ppm	0.05	1	<0.05	<0.05	<0.05	<0.05
			4	<0.05	<0.05	<0.05	<0.05
Copper	ppm	1	1	0.51	0.50	0.46	0.33
			4	0.34	0.25	0.22	0.17
Iron	ppm	0.30	1	0.76	0.86	1.11	0.92
			4	0.06	<0.05	<0.063	<0.05
Lead	ppm	0.05	1	0.20	0.10	0.043	0.17
			4	0.02	0.02	0.023	0.03
Magnesium	ppm	None	1	4.40	4.10	5.10	3.53
			4	0.07	0.07	0.19	0.15
Manganese	ppm	0.05	1	<0.05	<0.05	<0.06	<0.05
			4	<0.05	<0.05	<0.05	<0.05
Nickel	ppm	None	1	<0.10	<0.10	<0.10	<0.10
			4	0.34	0.10	<0.10	<0.10
Selenium	ppm	0.01	1	<0.01	Not performed		
			4	<0.01	<0.01	<0.01	<0.01
Silver	ppm	0.05	1	<0.05	<0.05	<0.05	<0.05
			4	<0.05	<0.05	<0.05	<0.05
Zinc	ppm	5	1	0.30	0.30	0.64	0.72
			4	0.05	0.03	0.065	0.043

TABLE III.- SUMMARY OF CHEMICAL AND PHYSICAL WATER DATA – Continued

(b) Ions

Parameter	Unit	U.S. Public Health Standard	Sample port (see fig. 1)	Baseline test 1, tap water	Baseline test 2, tap water and detergent	Test 3, wash water	Test 4, wash water
Ammonia	ppm	None	1	0.2	0.5	0.88	1.37
			4	2.5	1.3	1.18	1.30
Calcium	ppm	None	1	28	28	30	29
			4	0.2	0.2	0.9	0.7
Chloride	ppm	250	1	31	46	46	41
			4	<5	<5	<5	<5
Cyanide	ppm	0.20	1	<0.02	<0.02	<0.02	<0.02
			4	<0.02	<0.02	<0.02	<0.02
Fluoride	ppm	1.70	1	0.75	0.86	0.77	0.80
			4	<0.10	<0.10	<0.10	<0.10
Nitrate and nitrite	ppm	45.0	1	0.4	0.4	<0.3	<0.2
			4	0.3	<0.2	<0.2	<0.2
Phosphates	ppm	None	1	0.4	100	114	93
			4	0.1	<0.1	<2.2	1.4
Sulfate	ppm	250	1	12	74	70	79
			4	<5	<5	<5	<5

TABLE III.- SUMMARY OF CHEMICAL AND PHYSICAL WATER DATA – Concluded

(c) Organic and physical

Parameter	Unit	U.S. Public Health Standard	Sample port (see fig. 1)	Baseline test 1, tap water	Baseline test 2, tap water and detergent	Test 3, wash water	Test 4, wash water
Organic							
Carbon chloroform extract	ppm	0.50	1 4	<10 <10	<10 <10	51 <11	78 <10
Methylene blue active substances	ppm	0.20	1 4	0.04 <0.01	27 0.02	28 0.15	26 0.09
Phenols	ppm	0.001	1 4	Analysis not performed			
Total organic carbon	ppm	None	1 4	7 18	40 <5	146 <8	103 5
Urea	ppm	None	1 4	<1 <1	<1 <1	<2 <1	<3 <1
Physical							
Color	$PtCl_6$ equivalent units	15	1 4	30 <5	50 <5	>100 <6	>100 <5
Conductivity	Micromhos per unit	None	1 4	225 9	440 6	525 22	462 20
Odor	Threshold number	3.00	1 4	<3 <3	<3 <3	>3 <3	>3 <3
pH	pH	None	1 4	7.8 5.7	9.1 4.7	7.1 6.3	7.4 6.5
Total solids	ppm	500	1 4	206 <100	501 <100	782 <132	721 <100
Turbidity	ppm, SiO_2 equivalent units	5.0	1 4	8.30 0.63	41 0.27	259 2.78	213 1.63

TABLE IV.- WATER ANALYSIS TECHNIQUES

Parameter	Unit	Lower detection limit	Measurement technique
Arsenic	ppm	0	Atomic absorption
Barium	ppm	1	Atomic absorption
Cadmium	ppm	0.005	Atomic absorption
Chromium	ppm	0.01	Atomic absorption
Copper	ppm	0.10	Atomic absorption
Iron	ppm	0.05	Atomic absorption
Lead	ppm	0.05	Atomic absorption
Magnesium	ppm	0.001	Atomic absorption
Manganese	ppm	0.01	Atomic absorption
Nickel	ppm	0.20	Atomic absorption
Selenium	ppm	0.05	Atomic absorption
Silver	ppm	0.01	Atomic absorption
Zinc	ppm	0.05	Atomic absorption
Ammonia	ppm	0.20	Atomic absorption
Calcium	ppm	0.10	Atomic absorption
Chloride	ppm	5	Specific ion electrode
Cyanide	ppm	0.02	Specific ion electrode
Fluoride	ppm	0.10	Specific ion electrode
Nitrates and nitrites	ppm	0.50	Colorimetric
Phosphates	ppm	0.05	Colorimetric
Sulfate	ppm	5	Colorimetric
Methylene blue active substances	ppm	0.01	Colorimetric
Chloroform extract	ppm	10	
Phenols	ppm	0.01	Colorimetric
Total organic carbon	ppm	5	Combustion infrared
Urea	ppm	50	Colorimetric
Color	$PtCl_6$ equivalent units		Colorimetric
Conductivity	Micromhos per centimeter	0.40	Electrometric
Odor	Threshold number		Subjective
pH	pH		pH meter
Total solids	ppm	100	Flash evaporation
Turbidity	ppm, SiO_2	0.10	Turbidimetry

TABLE V.- SUMMARY OF MICRO-ORGANISM DATA

Sample port (see fig. 1)	Micro-organism measurement of –			
	Average total cells (no standard)		Average coliform cells (standard* is <4/100 ml)	
	Number/ml	Range	Number/100 ml	Range
1	2.3×10^6	10^5 to 10^6	9.1×10^6	10^3 to 10^7
2	$>3.1 \times 10^5$	10^4 to 10^5	$>6.5 \times 10^5$	0 to 10^6
3	1.1×10^4	0 to 10^4	0.2×10^0	0 to 10^0

*U.S. Public Health Standard, see reference 5.

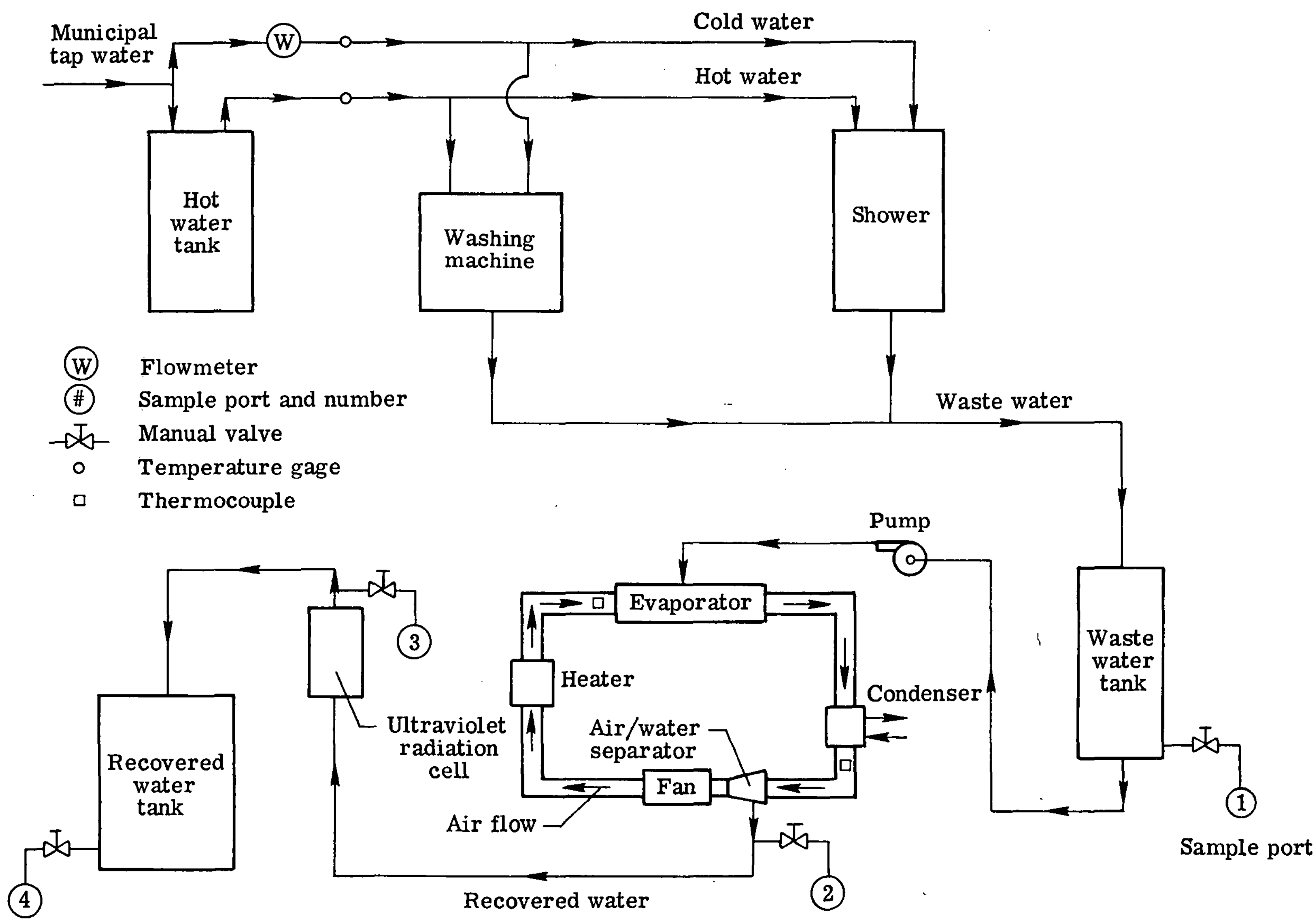

Figure 1.- Schematic drawing of test setup.

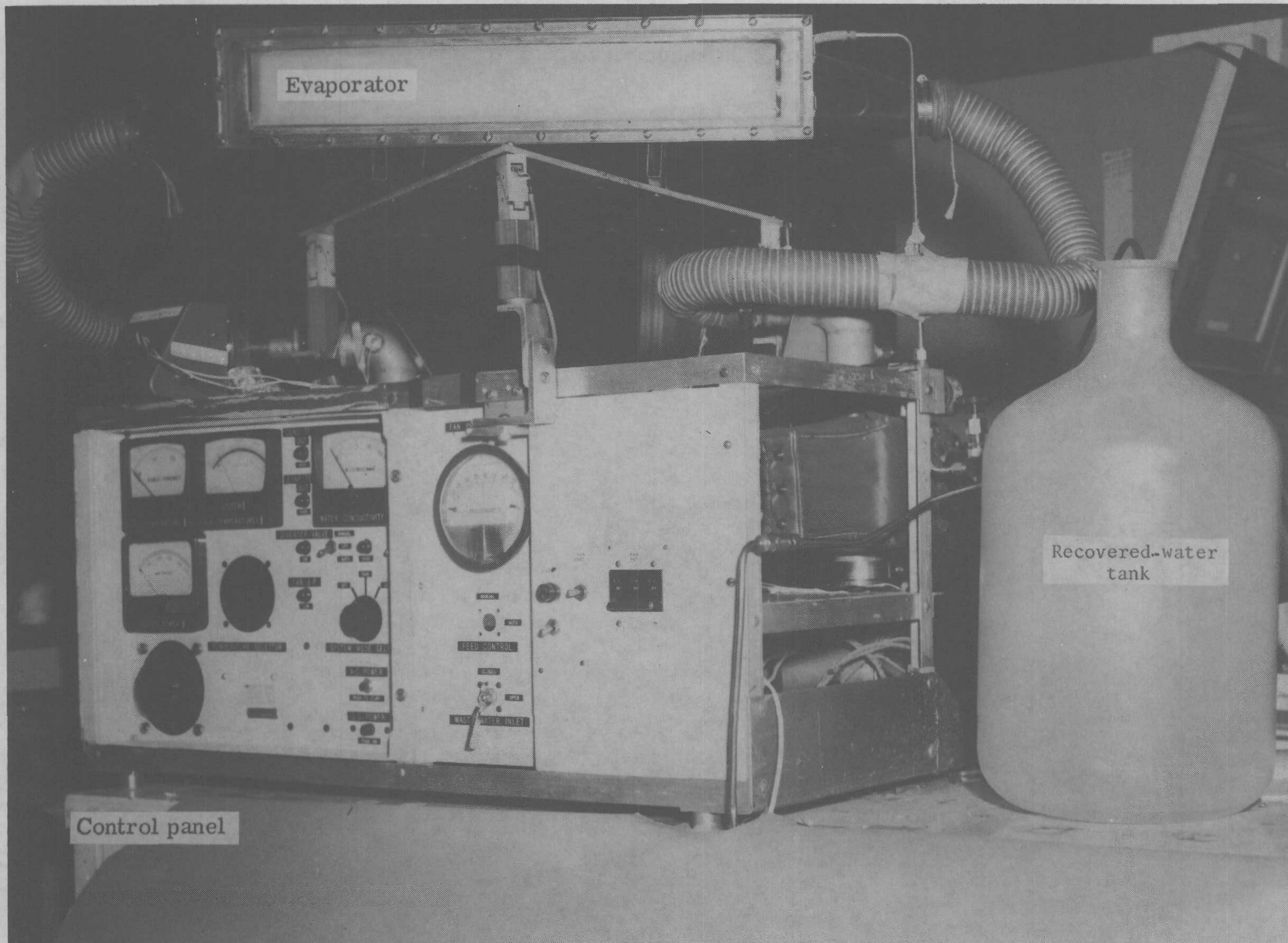

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Figure 2.- Water recovery subsystem.

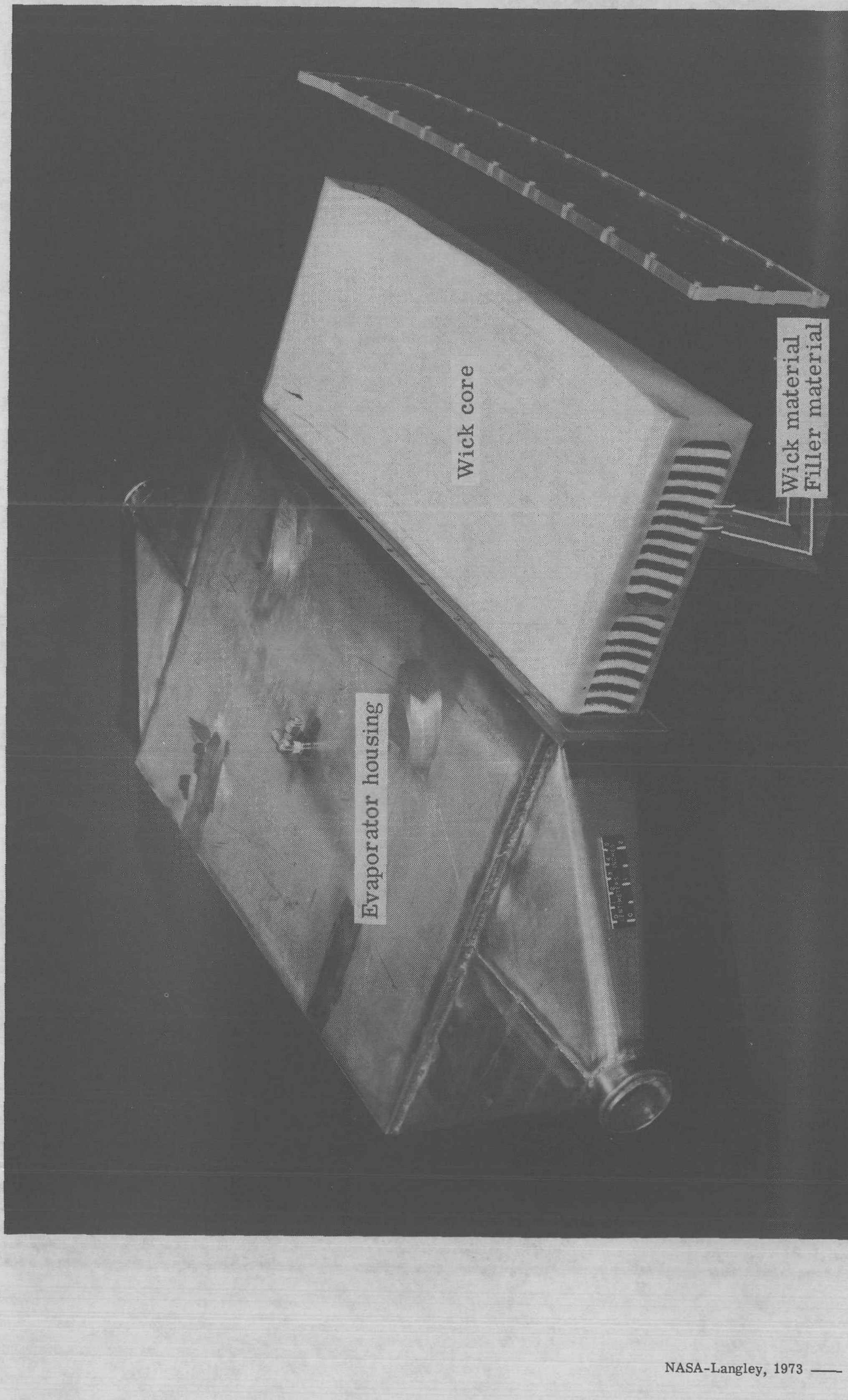

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Figure 3.- Evaporator housing and wick core.

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